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A STUDY OF THE SEASONAL VARIATION OF RADIO-FREQUENCY PHASE DIFFERENCE OF LAMINATED PHENOLIC INSULATING MATERIALS

By J. L. Preston and E. L. Hall

ABSTRACT

In measurements of radio-frequency properties of laminated phenolic insulating materials, the results of which are published in Bureau of Standards Technologic Paper No. 216, Properties of Electrical Insulating Materials of the Laminated, Phenol-Methylene Type, some samples were found to exhibit changes in these properties with time. The apparent change of radio-frequency phase difference or power factor of these samples with season of year led to the work described in the present paper, which is a study made in 1920–21 on some representative samples to learn whether the variations with season follow any definite trend. Incidentally, data on variation of phase difference with frequency are presented.

From observations made on 13 samples at approximately 60-day intervals over a period of 1 year, the following conclusions may be deduced:

(*a*) The phase difference or power factor of these samples varied with the season of year, reaching a maximum in late summer, and, in general, lagging behind the seasonal variations of atmospheric humidity and temperature.

(*b*) In general, the phase difference or power factor returned to its original value after undergoing a year's cyclic changes. A few of the samples showed a slight increase at the end of the year.

(*c*) The phase difference or power factor of these materials varied slightly with the frequency of the radio-frequency current. The variations with frequency between 100 and 600 kc were greater than the variations with season, for most but not all of the samples.

(*d*) The phase differences or power factors of any pair of samples of first-grade materials of the same make and color were found to differ more from each other than the amount of the seasonal variation. For the second-grade materials the seasonal variation was greater than the difference between samples.

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I. INTRODUCTION

In measurements of radio-frequency properties of laminated phenolic insulating materials, the results of which are published in Bureau of Standards Technologic Paper No. 216,[1] some samples were found to exhibit changes in these properties with time. Some of these changes were evidently an aging effect in samples which had not been completely cured during manufacture, while others were apparently changes dependent upon the season of year. These seasonal changes led to the work described in the present paper, which is a study of the radio-frequency phase difference or power factor of some representative samples to learn whether the variations with season follow any definite trend. Incidentally, data on variation of phase difference with frequency are presented. The measurements covered a period of one year, from March, 1920, to March, 1921. This work indicates the desirability of more studies along these lines. Valuable data could be secured by a study of more samples under conditions of separately controlled humidity and temperature.

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[1] Properties of Electrical Insulating Materials of the Laminated, Phenol-Methylene Type, by J. H. Dellinger and J. L. Preston; 1922.

II. PROCEDURE

Thirteen samples, made by four different manufacturers, were selected for study. Where possible, two samples each, of both first and second "grades" of each kind of material, were selected; one from the earliest shipment received from the manufacturer, the other from shipments received somewhat later. Samples of the first grade contain a larger percentage of phenolic varnish and are better suited for electrical insulating purposes than samples of the second grade, which excel in mechanical properties. The following table describes the samples:

TABLE 1.—*Description of samples tested*

Sample number	Manufacturer	Grade[1]	Color	Approximate thickness		Date received
				Inch	*cm*	
A1a	A	1a	Black	¼	0.64	Mar. 26, 1918
A2a		2a	do	¼	.64	Sept. 20, 1918
A3b		3b	Natural	¼	.64	Apr. 27, 1918
A4b		4b	do	¼	.64	Sept. 20, 1918
B5a	B	5a	do	½	1.28	Sept. 14, 1918
B6a		6a	Black	½	1.28	May 14, 1919
B7b		7b	do	¼	.64	Sept. 14, 1918
B8b		8b	Natural	¼	.64	May 14, 1919
C9a	C	9a	Black	¼	.64	Aug. 31, 1918
C10a		10a	do	¼	.64	Aug. 24, 1919
D11a	D	11a	do	¼	.64	Dec. 20, 1917
D12a		12a	do	¼	.64	Jan. 21, 1919
D13c		13c	do	¼	.64	Aug. 10, 1918

[1] *a* Considered in this paper as first grade; *b* and *c* considered in this paper as second grade; *c* differs from *a* in more points than *b*.

The samples were kept in a closed cabinet when not actually being measured, so they probably were not subjected to as rapid variations of temperature and humidity as they would have been had they been left exposed in the room.

The radio-frequency phase difference (or power factor) and dielectric constant of each sample were measured at five frequencies, at periods approximately two months apart, and curves plotted using frequency as the abscissa. A record was kept of the relative humidity and temperature at the time each sample was tested. In making measurements of phase difference or power factor at radio frequencies samples measuring 25 by 31 cm (10 by 12 inches) by the natural thickness of the material were used.

A glass dish was filled with mercury and the sample floated on the mercury surface in such a way as to eliminate all air pockets possible. A two-piece wire ring was then laid on the sample and the inclosure filled with mercury, thus forming a condenser consisting of two sheets of mercury with the sample of insulating material between. The equivalent resistance of the condenser made up of the sample under test was determined by the resistance variation method.[2]

Phase difference in degrees ($\psi°$) is then calculated from the equation

$$\psi° = 3.60\ RCf \times 10^{-7}$$

where

R = equivalent resistance of test condenser in ohms
C = capacity of test condenser in micromicrofarads
f = frequency in kc per second.
Power factor in per cent = $1.75\ \psi°$

The dielectric constant K may also be obtained from the same measurement of capacity, using the equation

$$K = \frac{CT}{0.0885\ S}$$

where

T = thickness of sample in cm
S = area of the upper condenser plate in cm^2
C = capacity of test condenser in micromicrofarads.

Values of phase difference computed by the above equation are correct where the values computed are small. An angle of 3°, computed by this equation, is about 0.1 per cent larger than the correct value, while an angle of 10° is about 1 per cent larger than the correct value. The majority of the insulating material used in radio panels has an average phase difference of less than 5°.

The data for the curves of phase difference (figs. 2 to 5) at the given frequencies of 600, 300, 200, 150, and 100 kc (wave lengths of 500, 1,000, 1,500, 2,000, and 3,000 m) were taken from curves plotted from the original data. This intermediate step was necessary because fixed inductors were used with the fixed condensers made up of the test samples to form the tuned radio-frequency circuit. These circuit frequencies were not usually, therefore, exactly the ones at which phase difference measurements were desired. The phase differences of these samples were determined at five frequencies, above, below, and between the required extremes and the values plotted as curves. The values of phase difference at a desired frequency were then read from these curves. A typical chart is shown in Figure 1.

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[2] Details of the method of determining the radio-frequency phase difference as well as other properties of electrical insulating materials are given in Bureau of Standards Scientific Paper No. 471, Methods of Measurement of Properties of Electrical Insulating Materials, by J. H. Dellinger and J. L. Preston; 1923.

The temperature and relative humidity of the air in the laboratory were observed at the time the electrical measurements were made.

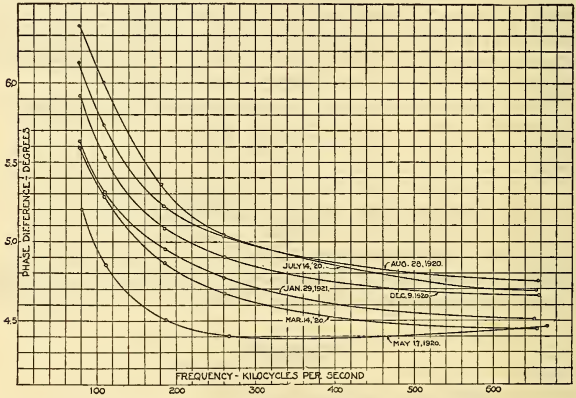

Fig. 1.—*Curve showing relation between phase difference and frequency at several times of the year for one sample of phenolic electrical insulating material* (*No. C–10–a*)

Curves for some samples have an upward trend instead of the downward trend here shown.

A curve showing the average humidity and a curve showing the average temperature were plotted from these data and are given on each of Figures 2 to 5. For comparison the figures also show curves of mean outdoor humidity and temperature for the same period, as observed by the United States Weather Bureau for Washington, D. C. These curves are, of course, different from the curves of indoor temperature and humidity but these are, in part, determined by the outdoor atmospheric conditions.

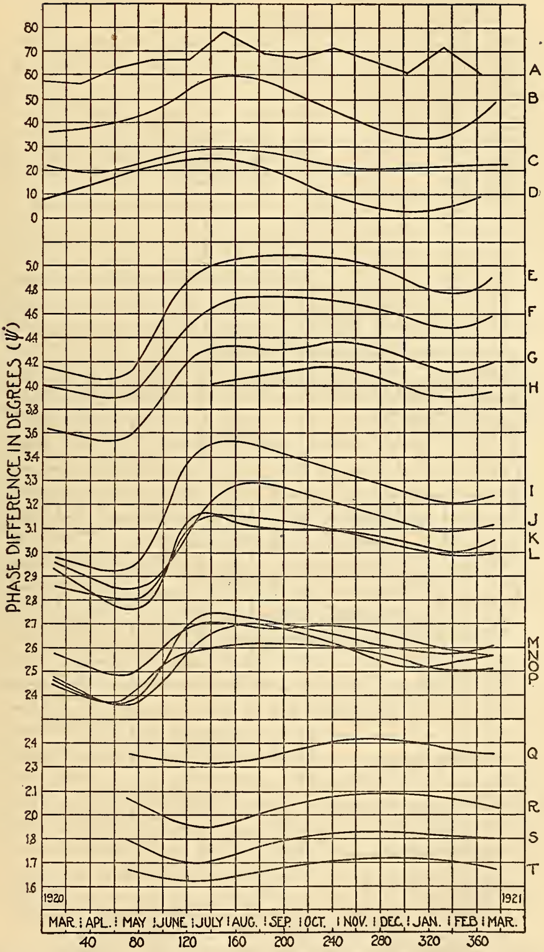

Fig. 2.—*Variations of phase difference with season, samples D12a, A2a, A1a, A3b*

Curve A, mean per cent relative humidity outdoors, from Weather Bureau records; curve B, average per cent relative humidity in laboratory; curve C, average temperature in laboratory; curve D, mean temperature outdoors, from Weather Bureau records; curves E, F, G, H, phase difference at 100, 150, 300, 600 kc, respectively, sample D12a; curves I, J, K, L, phase difference at 100, 150, 300, 600 kc, respectively, sample A2a; curves M, N, O, P, phase difference at 100, 600, 150, 300 kc, respectively, sample A1a; curves Q, R, S, T, phase difference at 600, 300, 150, 100 kc, respectively, sample A3b.

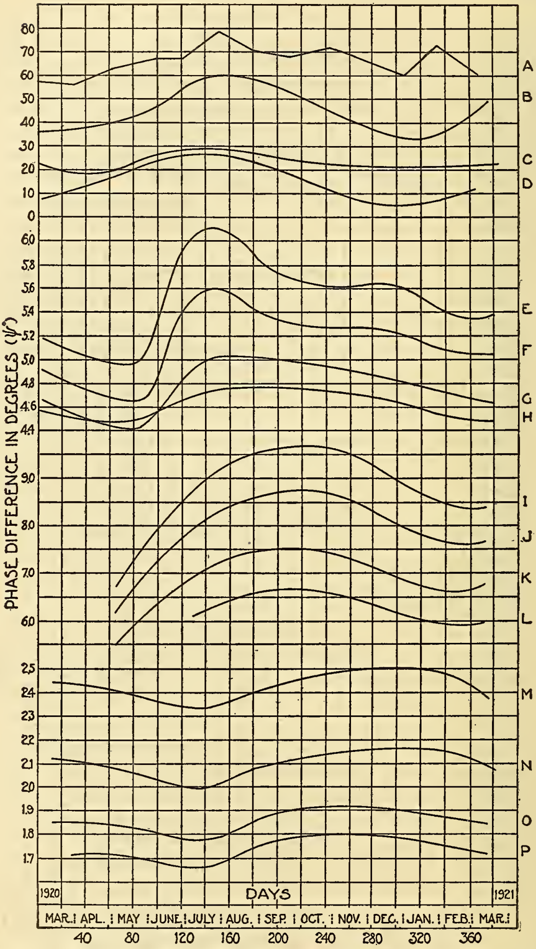

FIG. 3.—*Variations of phase difference with season, samples C10a, D11a, A4b*

Curve A, mean per cent relative humidity outdoors, from Weather Bureau records; curve B, average per cent relative humidity in laboratory; curve C, average temperature in laboratory; curve D, mean temperature outdoors, from Weather Bureau records; curves E, F, G, H, phase difference at 100, 150, 300, 600 kc, respectively, sample C10a; curves I, J, K, L, phase difference at 100, 150, 300, 600 kc, respectively, sample D11a; curves M, N, O, P, phase difference at 600, 300, 150, 100 kc, respectively, sample A4b.

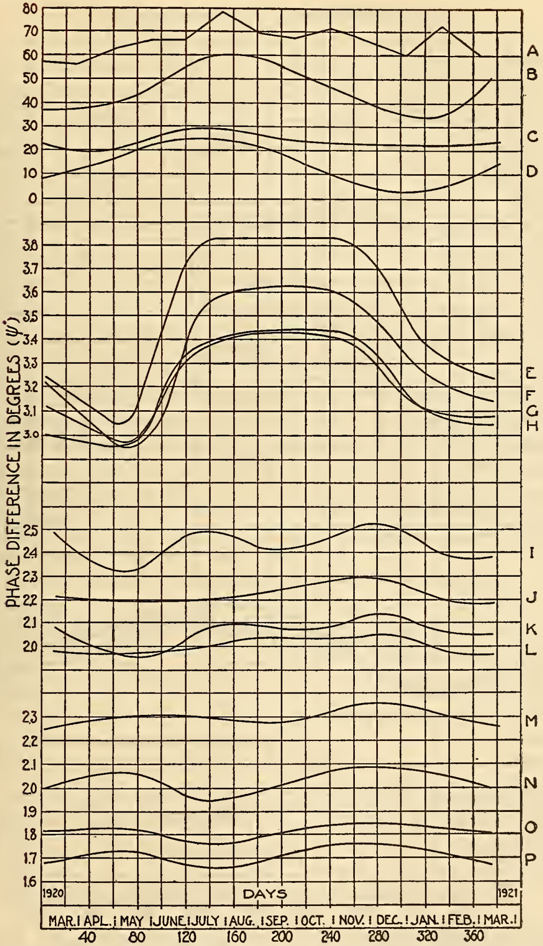

FIG. 4.—*Variations of phase difference with season, samples B7b, C9a, B8b*

Curve A, mean per cent relative humidity outdoors, from Weather Bureau records; curve B, average per cent relative humidity in laboratory; curve C, average temperature in laboratory; curve D, mean temperature outdoors, from Weather Bureau records; curves E, F, G, H, phase difference at 100, 150, 600, 300 kc, respectively, sample B7b; curves I, J, K, L, phase difference at 600, 300, 150, 100 kc, respectively, sample C9a; curves M, N, O, P, phase difference at 600, 300, 150, 100 kc, respectively, sample B8b

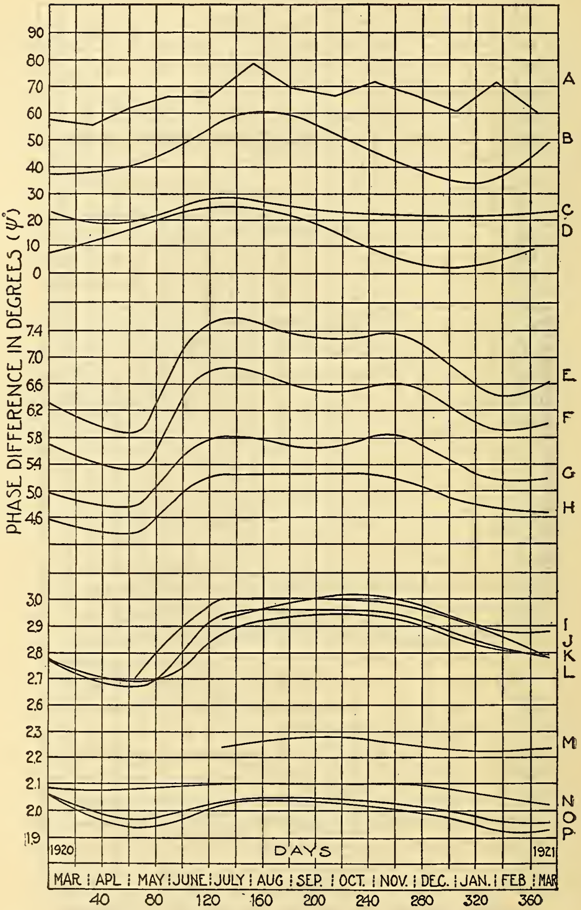

FIG. 5.—*Variations of phase difference with season, samples D13c, B5a, B6a*

Curve A, mean per cent relative humidity outdoors, from Weather Bureau records; curve B, average per cent relative humidity in laboratory; curve C, average temperature in laboratory; curve D, mean temperature outdoors, from Weather Bureau records; curves E, F, G, H, phase difference at 100, 150, 300, 600 kc, respectively, sample D13c; curves I, J, K, L, phase difference at 600, 150, 300, 200 kc, respectively, sample B5a; curves M, N, O, P, phase difference at 600, 300, 200, 150 kc, respectively, sample B6a.

III. DISCUSSION AND CONCLUSIONS

The behavior of the samples as they undergo seasonal changes is what would be expected from numerous observations that have been made on samples of which the temperature and moisture conditions were deliberately varied. In all such cases the radio-frequency phase difference was found to increase after a sample had been subjected to conditions of humidity and was found to decrease after moisture had been expelled by a heating process. Limited experiments have also shown that the radio-frequency phase difference increases with increase of temperature. It would, therefore, be expected that, in general, a prolonged period of high atmospheric humidity and temperature would tend toward an increase of phase difference. This is corroborated by the curves (figs. 2 to 5) which show that, in general, the maxima of phase difference followed the maxima of humidity and temperature. Conditions inside the insulating material naturally lag a considerable time with respect to the conditions of the surrounding air. The separate effects of humidity and temperature are not shown by these curves. The effects may have been further complicated by an unknown amount of aging; that is, gradual curing or completion of processes used in manufacture in some of the samples. As a result no certain conclusions can be drawn as to the separate effects of humidity and temperature and aging on the several materials. All the variables were effective simultaneously, and at times some of the variables may have tended to increase and the others to decrease the phase difference.

While the phase differences of most of the samples were higher during the summer months, when high humidities and temperatures prevailed, than during the winter months, the phase difference curves of three of the samples vary in opposition to the variations of both temperature and relative humidity. These three samples are of second-grade material (see Table 1 for statement as to which are second-grade materials) and are capable of absorbing about six times as much water under similar conditions as first-grade materials of the same make. It is probable, therefore, that the humidity effect predominates owing to greater porosity. In these cases the low portions on the phase difference curves were probably the result of the lower temperatures and humidities indicated by the preceding low portions on the temperature and humidity curves.

In general, the phase difference returned to its original value after undergoing a year's cyclic changes. More specifically, the curves show the following results at the end of the year:

(*a*) The phase difference of 8 of the 13 samples was within 0.1° of the original value at three or more frequencies.

(*b*) The phase difference of one sample increased more than 0.1° at two frequencies and decreased 0.1° at one frequency.

(*c*) The phase difference of four samples increased 0.1° or more at three or more frequencies.

The effect of frequency on phase difference is, in these materials as in others,[3] a second-order effect, the variations with frequency being small. Some of the samples, both first and second grade, showed an increase of phase difference with frequency while others showed a decrease. The variations with frequency between 100 and 600 kc were greater than the variations with season for most but not all of the samples.

The phase differences of any pair of samples of first-grade materials of the same make and color were found to differ from each other by more than the amount of the seasonal variation. For the second-grade materials the seasonal variation was greater than the difference between samples.

WASHINGTON, September 11, 1924.

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[3] G. E. Bairsto, "On the variation with frequency of the conductivity and dielectric constant of dielectrics for high-frequency oscillations," Proc. Roy. Soc., January 2, 1920. E. T. Hoch, "Power loss in insulating materials," Bell System Technical Journal, November, 1922. H. J. MacLeod, "Power loss in dielectrics; variation with frequency," Phys. Rev., January, 1923.

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